UCRL-52409-1

ENEWETAK RADIOECOLOGY RESEARCH PROGRAM: I. ECOLOGICAL STUDIES ON ENGEBI ISLAND 1975-76

John J. Koranda, William L. Robison,
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Work performed under the auspices of the U.S. Department of Energy by the UCLLL under contract number W-7405-ENG-48.

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CONTENTS

ENEWETAK RADIOECOLOGY RESEARCH PROGRAM: I. ECOLOGICAL STUDIES ON ENGEBI ISLAND 1975-76

ABSTRACT

As part of the Lawrence Livermore Laboratory Enewetak Radioecology Research Program, we studied radionuclide cycling from soil to plant to soil on Engebi Island at the Enewetak Atoll. Mature and dying leaves, young and old litter, humus, and soil beneath these organic strata were collected from 1975-76 at three Engebi sites. To study radionuclide depth distributions, five trenches of >1 m were dug and sampled. From three representative sites, we found that ^{137}Cs rapidly cycles from the plant biomass through the litter and humus into the vegetation. Continuously deposited litter decomposes within 6 to 12 months, but the constituent radionuclides are released early during physical decomposition. Soil radionuclides generally occur in the upper 40 cm of the soil profile, strongly associated with the organic horizon. Radionuclides such as ^{60}Co, $^{152\text{-}155}$Eu, ^{207}Bi, and ^{241}Am are complexed in the finely divided organic matter or humus where ^{137}Cs and ^{40}K predominate. Our data suggest that there is a circulating pool of rapidly cycling ^{137}Cs in the Engebi ecosystem that may be entirely associated with the plant biomass and organic strata of the soil. Soil-bound radionuclides below the humus are low in concentration and may not enter into this pool because they are below the vegetation root zone, where they may be leached by rainwater. This information is needed in making realistic long-term radionuclide dose assessments for the Enewetak peoples.

INTRODUCTION

Subsequent to an extensive radiobiological survey of Enewetak Atoll in 1972-73,[1] we are studying radionuclide transport from soil to edible plants in the terrestrial Enewetak ecosystem. In this study, the Enewetak Radioecology Research Program, we use this information in making realistic radionuclide dose assessments for the Enewetak peoples subsisting by some form of tropical agriculture. The results of the 1972-73 survey and assessment indicate that the most significant potential pathway of radionuclide transfer to a returning Enewetak population could be through the terrestrial foodchain. A prominent feature of this trophic transfer of radionuclides from vegetation to man is that many plants can accumulate or concentrate radionuclides in their leaves and fruits several times over that present in the root-zone soil.[2,3]

Many habitats of Enewetak Atoll are still recovering ecologically so that many food species are absent either because they have not reinvaded areas denuded in the 1950's or because they have not been reintroduced by man, like the coconut. Therefore, we designed our program to provide information in two areas:

1. The natural environmental cycling of radionuclides from soil to plant and back to soil.
2. The uptake, incorporation, and concentration of radionuclides by food plants grown in areas where radioactivity levels are known.

This report, a first in a series for the Enewetak Radioecology Program, describes the first subject; the second subject will be discussed in a subsequent report.

Our research was conducted in 1975 and early 1976 (the first 18 months of the Program) on Engebi Island in the northern part of Enewetak Atoll (see Fig. 1). A schedule of our field activities on Engebi Island in 1975-76 is shown in Table 1. We measured in plants and soil the levels of the gamma-emitting radionuclides cobalt-60 (^{60}Co), antimony-125 (^{125}Sb), cesium-137 (^{137}Cs), europium-152,155 (^{152,155}Eu), bismuth-207 (^{207}Bi), and americium-241 (^{241}Am). Naturally occurring potassium-40 (^{40}K) was also analyzed in plants because

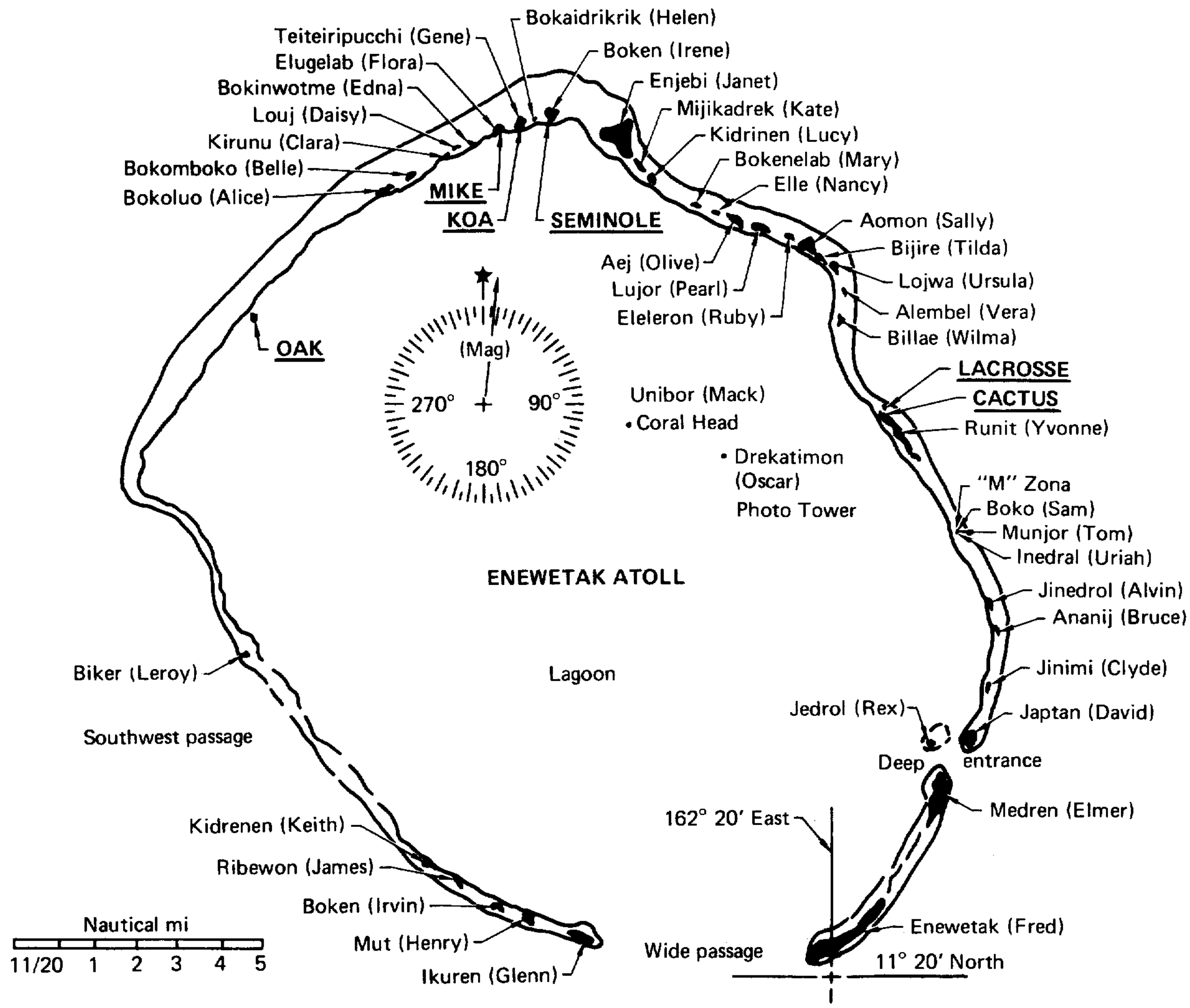

Fig. 1 Map of Enewetak Atoll.

potassium metabolism often tells us about the basic physiology of the plant. Wet chemistry analyses for strontium-90 (^{90}Sr) and plutonium-239-241 ($^{239\text{-}241}Pu$) concentrations in ecological and agricultural samples have not been completed and will be the subject of a future report.

Table 1. Schedule of research activity at Enewetak Atoll Feb. 1975 - Feb. 1976.

Date	Activity
February 1975	Establishment and clearing of large plot area for food species; excavation of soil profile trenches; initial ecological collections.
May 1975	Rain collection reservoirs installed.
July 1975	Planting of food plants in large plot area; hauling of low-activity soil from southern part of atoll; second ecological sample collections made.
October 1975	Rodent control to prevent water reservoir damage resulting in crop loss; watering technique developed; harvest of vegetables and short-lived plants in food species plots; third series of ecological collections made.
February 1976	Harvest of food species in small plot area; large in-ground water reservoir constructed; ecological sample series collected; biomass studies begun.

METHODS

Plant and soil samples were collected in the field by conventional methods, although some large excavation equipment was used to obtain soil profile samples (to 1.5-m depth) in the consolidated subsurface coral.

When available, plants and fruits were collected into large paper bags and dried. A 2- to 3-kg sample of vegetation was taken from the entire canopy of the tree sampled and represents the plant's foliage as a whole. The plant samples were dried in a forced-draft oven at 70 to 80°C and ground in a large Wiley mill with a 2-mm sieve.

We collected recently fallen plant leaves (litter) to investigate radionuclide transfer from vegetation to the soil. To evaluate our collection methods, litter-fall measurements were made using three types of collectors. Plant litter was collected in 41- × 48-cm plastic trays from January 1975 to February 1976. We have since used 45- × 105-cm wire baskets. We found that the surface of polypropylene mesh bags used for litter decomposition studies (discussed below) also served as efficient litter-fall collectors.

We determined standing litter inventories by collecting litter from measured areas beneath the sampled trees at the beginning and end of the experimental period (January to July 1975, and July 1975 to February 1976). The litter samples were collected to the top of the humus layer and constitute all of the leafy litter from 50- × 50-cm areas. This sample, called the raw litter layer, is the portion of the total litter deposit in which leaves maintain their general form, although they are wrinkled, somewhat dissected, and have not yet become the finely divided brown humus that underlies the raw litter layers.

To determine the rate of leaf decomposition, plastic bags made of a coarse polypropylene mesh (12- × 22-mm) were loaded with 1 kg of fresh leaves and placed beneath the trees where other samples were collected. The entire litter layer was hand-collected from measured 50- × 50-cm areas at these sites to obtain litter densities and concentrations of radionuclides per unit area of ground surface.

We collected soil samples beneath the trees to a 25-cm of more depth to determine coefficients of soil-plant uptake and to measure the transfer of radionuclides from the organic strata into the soil. Coral may become consolidated below depths of 50 cm, and sampling with hand tools is difficult if not impossible. The results of the previous radiobiological survey [1] indicated that maximum radionuclide concentrations in undisturbed habitats on Engebi Island occur in the surficial strata (horizons) of the soil.

Gamma-emitting radionuclides were analyzed by solid-state gamma ray spectrometry by methods essentially the same as reported in the NVO-140 report [1] and by Phelps et al.,[4] Koranda et al.,[5] and Prindle.[6] In this study, we used the plant taxonomy scheme according to St. John.[7]

RESULTS AND DISCUSSION

Summary of 1972-73 Survey Data for Engebi Island

In the previous radiobiological survey, data on the levels and distribution of radionuclides on Engebi Island were investigated. The pertinent data we obtained on Engebi Island from this study can be related to study sites in the present study (Fig. 2). Sector D is near the Lee site, a triangulation station, which is now being studied. Sector E and I are at the edges of the subsistence crop experimental plot established in July 1975. The soil and plant data from 1972-73 [1] at these sites are summarized in Tables 2 and 3.

Soil radionuclide concentrations on Engebi Island vary from site to site; for example, ^{137}Cs ranges from 6.5 to 180 pCi/g in samples collected in 1973 in the vicinity of our present study sites. On a dry weight basis, plants usually contain more ^{137}Cs and less ^{90}Sr activity than the soil. However, in the 1972-73 survey, the soil samples were not taken at the root zone of the sampled trees.

Soil and Plant Data from Follow-up Research Program of 1975

In January 1975, five trenches were dug on Engebi Island to determine the depth profile of radionuclide concentrations in soil around the area chosen for establishing test plots of food plants. These trenches designated BDFP-1 through -5, are shown as numbers 1-5 in Fig. 2.

Native vegetation adjacent to trench BDFP-1 and on most of Engebi Island consists of open woodlands of *Messerschmidia argentea* (Boraginaceae, Fig. 3) and *Scaevola frutescens* (Goodeniaceae) with a ground cover of the sedge *Fimbristylis atollensis*, the morning glory *Ipomoea pes-caprae*, and occasional clumps of the shrub *Pluchea odorata* (Compositae). Leaves, litter, and

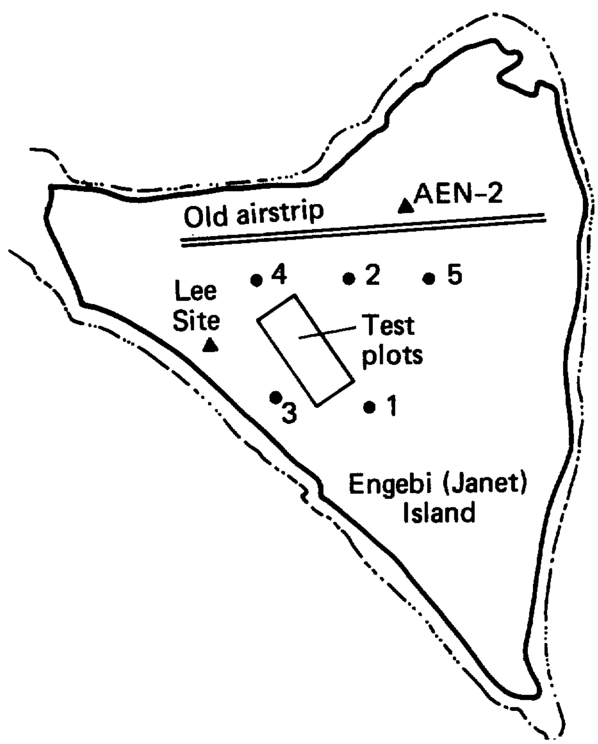

Fig. 2. Diagram of Engebi Island showing trenches, plots, and study sites.

Fig. 3. *Messerschmidia argenta* tree showing growth form.

Table 2. Soil and plant radionuclide concentrations from NVO-140 Report samples collected on Engebi Island.

	pCi/g dry wt.				
Area and sample	^{40}K	^{60}Co	^{90}Sr	^{137}Cs	$^{239+240}Pu$
Sector D (near Lee site)					
Soil sample					
No. 131	–	4.5	95	42	2.5
Plants					
Messerschmidia argentea	15	–	120	160	0.0029
Pluchea odorata	11	1.3	47	1600	–
Sector E (east of food-species plots)					
Soil samples					
No. 58	–	1.5	140	78	23
No. 61	–	2	45	47	9
No. 62	–	1	120	56	28
Plants					
Messerschmidia	12	–	84	300	0.005
Scaevola frutescens	14	0.45	36	220	0.003
Sector I (south of food-species plots)					
Soil samples					
No. 118	–	0.43	18	6	3.5
No. 125	–	0.19	25	10	2.1
Plants					
Messerschmidia	13	–	18	36	0.015
Scaevola	17	–	12	31	0.016

Table 3. Soil radionuclides concentrations (from NVO-140[1]) near present study sites on Engebi Island.

Soil sample No. (site to 15-cm depth)	pCi/g dry wt. ^{60}Co	pCi/g dry wt. ^{137}Cs
116, Lee	0.94	19
117, Lee	0.52	8.5
108, Trench No. 1	1.1	16
112, Trench No. 1	0.62	9.3
106, Trench No. 4	1.1	8.1
142, Trench No. 4	4.6	57
97, Trench No. 4	5.6	41
76, Trench No. 3	9.6	180
61, Trench No. 5	2.3	47
54, AEN-2 well	3.8	28
141, AEN-2 well	1.1	12
Soil depth for sample No. 142 (NW edge of food species plot), cm		
Surface	10	100
5	7.2	60
10	3.8	45
20	3.0	50
25	2.0	55
30	1.5	21
35	0.4	6.0
40	0.09	1.5
45	0.07	1.0
50	0.05	0.70
55	0.03	0.53
60	0.02	0.45
65	0.02	0.33
70	0.01	0.22
75	0.01	0.23
80	0.01	0.23
85	0.01	0.25
90	0.01	0.27
100	0.02	0.35

soil from beneath the tree canopy in the root zone of a large *Messerschmidia* tree (Fig. 3) chosen for repeated measurements were sampled adjacent to the trench BDFP-1. Mature (green) and recently fallen (yellow) leaves showed high ^{137}Cs and low ^{60}Co concentrations. Radionuclide concentrations in green leaves were about 4 to 6× soil concentrations beneath the tree. Two distinct ages of litter were apparent beneath *Messerschmidia* trees. Gray litter lying beneath the light brown litter is more physically decomposed and obviously older. Litter loses its ^{137}Cs activity rapidly as it decomposes, and ^{40}K is also apparently leachable from the litter. ^{40}K was not detected in the old, gray litter.

Trench BDFP-1

Table 4 lists radionuclide concentrations in the soil samples collected in trench BDFP-1 and from samples of the adjacent vegetation. The trench was sampled in each distinct horizon, the samples being representative of that horizon. The surface soil (0-18 cm) contained most of the radioactivity with a rapid fall off below 25 cm to near background levels at the maximum depth sampled. To a depth of 91 cm, the organic matter concentration ranged from 4 to 4.6% and pH values ranged from 8.3 to 8.9. At 112 cm, the soil consisted of partially consolidated coral; the organic matter was only 2.2% and the pH was very basic (9.0).

A relatively high concentration of ^{60}Co, 5.43 pCi/g, was found in the surface stratum of soil to 2.5-cm depth beneath the *Messerschmidia* tree at trench BDFP-1; however, ^{60}Co was lower in the trench that was in an open area a few meters from the tree. Concentrations of ^{137}Cs and ^{60}Co were highest in the soil beneath the tree. The organic matter content of the soil was 7.8%.

Trench BDFP-2

Radionuclides in the soil at trench BDFP-2 are shown in Table 5. Surface soil (0-18 cm) had the highest radionuclide concentrations. Organic matter was highest and pH the lowest in this stratum. The profile was stained with organic matter to 51-cm depth but the more obvious zone extended only to 25 cm. Radionuclide concentrations below the organically stained stratum (below 25 cm) were very low. The top 25 cm of the soil column contained over 95% of the activity observed in the 81-cm profile. Concentrations of ^{137}Cs decreased by almost 1.7-fold in the first 2.5 cm of the profile.

Vegetation collected near trench BDFP-2 contained high ^{137}Cs but low ^{60}Co concentrations (Table 6). *Messerschmidia* leaves rapidly lost ^{137}Cs and ^{40}K activity as they weathered and decomposed. Surface, humus-rich soil (0-5 cm) collected beneath the trees near trench BDFP-2, contained ^{137}Cs concentrations of 18% (*Messerschmidia*) and 7.8% (*Scaevola*) of the concentrations in the leaves of the trees at that location. Soil under trees also contained ^{60}Co concentrations that were high compared with concentrations in the adjacent trench. Apparently, ^{60}Co accumulates in the humus stratum below the raw litter layer underneath both species of trees. ^{60}Co is usually not detected in green leaves or raw litter; possibly, it is present in the humus because of leaching from the canopy and fresh litter, with subsequent accumulation in the humus layer and soil organic fraction. Humus is known to complex metals in temperate-region soils.

Table 4. Radionuclide concentrations in samples collected in the trench BDFP-1 area.

Sample depth, cm	pH	Organic matter, %	pCi/g dry wt.						
			^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{155}Eu	^{207}Bi	^{241}Am
				January 1975					
Soil samples									
0-5	8.4	4.2	0.35	1.4	0.25	21	1.6	0.56	4.4
0-5	8.3	4.1	–	1.3	–	18	1.6	0.56	2.5
0-18	8.5	4.6	0.38	2.7	0.84	40	3.4	0.12	11.2
18-23	8.9	4.0	0.43	0.12	–	8.3	–	–	–
25-91	8.4	4.6	0.28	0.04	0.32	1.2	–	–	0.11
>112	9.0	2.2	0.12	–	–	0.12	–	–	0.05
Vegetation (*Messerschmidia*) and associated soil samples									
Green leaves			18	0.12	1.5	280	–	–	–
Yellow leaves			19	–	–	380	–	–	–
Brown litter (young)			10	0.05	1.0	230	–	–	–
Gray litter (old)			–	0.23	—	44	–	–	0.25
Soil under *Messerschmidia* (0-2.5 cm)			–	5.4	1.2	64	6.3	1.3	10
Soil under *Messerschmidia* (2.5-15 cm)			–	1.7	–	43	1.5	0.16	2.7
				February 1976					
Vegetation (*Messerschmidia*) and litter samples									
Green leaves			15	–	–	160	–	–	–
Yellow leaves			13	–	–	220	–	–	–
Young litter			11	–	–	230	–	–	–
Old litter			–	–	–	64	–	–	–
Litter layer 50 × 50 cm			–	0.88	–	35	0.86	–	3.3
Litter layer 50 × 50 cm			–	0.88	–	33	0.93	0.23	3.5
Surface roots of tree			7.0	0.49	–	150	–	–	–

Foliar-leaching of radionuclides from leaves is also well-documented.[8] Complexation of ^{60}Co by the humus layer was also observed in the samples collected at trench BDFP-1.

A clump of *Pluchea odorata* grew in the bottom of trench BDFP-2, which was excavated in January-July 1975. Plant stems were more than 2 m tall in February 1976, about seven months later. A leaf sample was collected from the trench plant and another from a plant of *Pluchea* growing on the original surface of ground 75 m away from the trench. Soil in the bottom of the trench in January-July 1975 (Table 5 and 6) had less than 1 pCi/g ^{137}Cs, and at the February 1976 sampling, had 2.7 pCi/g. *Pluchea* leaves from the plant growing in the bottom of the trench on low activity soils had 330 pCi/g ^{137}Cs dry weight. Using the data from February (2.7 pCi/g soil), the concentration factor for this plant for ^{137}Cs would be 122 X. Possibly, this plant was using lens water that was within 1-2 m of the trench bottom. Several trenches were dug in this area to approximately 2-m depth and were found to have standing water in them, indicating that they communicated with a ground water source. The *Pluchea* growing 75 m from the trench on the surface of the ground had more than 2 X the ^{137}Cs concentration of the trench plant and its concentration factor was 13 X the surface soil. *Pluchea* typically has higher concentration factors than the other two common native species, *Messerschmidia* and *Scaevola*.

Trench BDFP-3

Radionuclide levels in trench BDFP-3 soil are shown in Table 7. This site appeared to have undergone subsurface disturbance in the past

Table 5. Radionuclide concentrations in plants collected near trench BDFP-2, January 1975.

Sample	pCi/g dry wt.						
	^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{241}Am
Messerschmidia, mature leaves (green)	20	–[a]	–	500	–	–	–
Messerschmidia, young litter (brown)	13	–	2.6	440	–	–	–
Messerschmidia, old litter (gray)	1.1	0.68	–	150	–	0.52	–
Soil under *Messerschmidia* 0-5 cm, pH 8.3, 9.0% om[b]	–	2.3	–	93	0.74	3.1	2.6
Soil under *Messerschmidia* 10-15 cm, pH 8.8, 5.2% om	–	6.3	0.75	47	0.70	8.9	11
Scaevola, green leaves	13	0.39	2.6	540	–	–	–
Scaevola, litter	2.5	0.33	–	340	–	–	–
Soil under *Scaevola* 0-5 cm, pH 8.2, 4.1% om	–	1.3	–	42	0.34	0.99	0.84
Soil under *Scaevola* 10-15 cm, pH 8.6, 4.2% om	–	4.9	1.1	51	0.40	3.6	2.6
Pluchea, green leaves in old trench	13	0.60	330	–	–	–	–
Pluchea, green leaves 75 m from trench on surface	9.1	0.40	770	–	–	–	–
Soil, bottom of 15.2 cm trench (6-in.)	–	0.20	2.7	–	0.25	–	0.62

[a]Not detected.

[b]Organic matter.

Table 6. Radionuclide concentrations in soil from trench BDFP-2, July 1975.

Soil sample	Depth, cm	Organic matter, %	pH	pCi/g dry wt.					
				^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{155}Eu	^{241}Am
Surface soil brown sand	0-2.5	7.1	8.1	0.24	2.7	0.69	61	3.3	3.9
Brown sand	2.5-5	5.4	8.6	–	6.1	1.3	35	5.4	3.4
Gray-brown sand with roots	5-7.5	5.1	8.3	–	5.7	1.0	75	6.6	5.1
Light gray sand[a]	10-18	3.5	8.8	–	0.92	–	26	0.99	0.99
Dark brown sand	18-25	6.9	8.2	0.78	0.23	0.39	8.2	0.08	0.21
Light brown sand with large coral fragments	38-50	1.7	9.0	0.40	–	–	0.15	–	0.09
Light tan, coral sand	71-81	3.7	9.5	0.59	–	–	0.12	0.02	0.07

[a]Weakly cemented, perhaps compacted by machinery.

Table 7. Radionuclide concentrations in soil near trench BDFP-3.

Sample (sand)/ depth, cm	pH	Organic matter, %	pCi/g dry wt. ^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{241}Am
White coral/ 0-25	8.2	8.1	–	4.4	0.45	51	0.42	4.7	6.5
Compacted coral/ 20-25	9.0	3.4	–	0.31	–	21	0.35	0.33	0.33
Tan coral/ 30-36	8.6	4.1	–	0.07	–	11	0.09	–	0.09
Dark brown/ 51-61	8.4	5.6	–	0.05	0.23	0.9	–	–	0.05
Light tan coral/ 71-76	8.8	3.7	–	–	–	0.06	–	–	0.05
White coral/ 122-127	9.3	2.2	–	–	–	–	–	–	–

(probably during the test period), and a compacted coral sand stratum was present at 20-25 cm depth. The low organic matter content and the high pH in soils at BDFP-3 suggests that beach sand was transported to this site. Fragments of asphalt were present on the surface of the ground. Radionuclides are concentrated in the surface (0-36 cm) of the soil. The dark brown stratum at 51-61 cm had low concentrations of radionuclides despite a high organic matter content, which may represent a buried soil surface horizon. The top 25 cm of soil contained over 85% of the total activity observed from the soil profile.

Trench BDFP-4

Trench BDFP-4 radionuclide soil data are listed in Table 8. This site showed little recent disturbance, and the profile may be considered representative for this portion of the island (Fig. 2). Soil surface horizons (0-20 cm) were high in radionuclides, low in pH, and high in organic matter. Soil contained ^{40}K but in sub-picocurie concentrations; ^{60}Co was not detected below 20 cm. The top 30 cm of the soil contained 90.3% of the radioactivity in the soil profile. At 71 cm depth, the soil was partially consolidated coralline limestone with a high

Table 8. Radionuclide concentrations in soil near trench BDFP-4.

Sample (sand)/ depth, cm	pH	Organic matter, %	pCi/g dry wt. ^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{241}Am
Dark brown coral with roots/ 0-7.5	8.5	5.0	0.31	3.4	0.82	25	0.06	3.4	9.7
Dark brown coral/ 10-15	8.6	4.2	0.51	0.28	–	16	–	0.09	0.31
Dark brown/ 15-20	8.6	4.5	0.65	0.15	–	4.5	–	0.03	0.20
Light brown/ 38-43	8.8	4.4	–	–	–	1.4	–	–	0.08
White coral/ 71-76	9.5	3.6	0.61	–	–	0.18	–	–	0.08

pH, low organic matter, and low concentrations of radionuclides.

Trench BDFP-5

Radionuclide concentrations from the soil in trench BDFP-5 are shown in Table 9. The characteristics of this trench are similar to BDFP-4, which is just west of BDFP-5. The top 15 cm of the soil contains 99.4% of the radioactivity. No ^{60}Co was detected below 20 cm and ^{40}K levels were low throughout. As shown in Fig. 2, trenches BDFP-4 and -5 are at the northern end of the experimental food species plots, and BDFP-1 and -3 are located at the southern and western edges, respectively.

Vegetation samples were collected at two other sites for studies of plant-soil radioactivity relationships (Fig. 2). One site was chosen at the northwest end of the island near a benchmark called Lee. Another site was selected midway along the old runway on the northern part of island adjacent to a ground or lens-water well (AEN-2).

Lee Site

Concentrations of radionuclides in vegetation and soils collected at the Lee site from February 1975 to October 1976 are shown in Table 10. Concentrations of ^{137}Cs in the leaves were 12 X (young leaves) to 20 X (basal leaves in cluster) the concentration in the surface 0-15 cm of the soil beneath *Messerschmidia.* Old, gray litter contained 11% of the ^{137}Cs concentration observed in mature, green leaves (basal), which would be the next to age and fall. The raw litter layer (all of the undecomposed leaf layer) had lost 95% of the ^{137}Cs activity found in the old, basal leaves, but had a slightly higher ^{60}Co concentration. This distribution of ^{60}Co has been observed at several other locations.

The humus layer also contains measurable concentrations of $^{152\text{-}155}Eu$, ^{207}Bi, and ^{241}Am, whereas these radionuclides are not detected in the green leaves or the young litter of the tree. Humus ^{137}Cs concentrations were 9-11% of the green leaf concentrations at the Lee site.

A litter profile was sampled beneath the *Messerschmidia* tree (No. 2) where we made litterfall measurements (Table 11). The total litter and humus biomass to 7.5-cm depth was 13 kg/m ^{2} dry wt, and the total ^{137}Cs in the profile was 0.66 μCi/m ^{2}. The litter layer and the humus beneath it is a large compartment in which radionuclides are absorbed and retained.

Soil radioactivity did not decrease in the 15 cm sampled beneath *Messerschmidia* tree.[2] Sampling was limited by the presence of indurated limestone materials but the profile sampled was highly organic. A *Scaevola* tree (Table 10) growing 4.6 m from the *Messerschimidia* tree at this site had lower leaf radioactivity. The same loss of radioactivity from the litter layer occurs in this species also. Leaves on *Scaevola* leaves are somewhat more succulent than those on *Messerschmidia* and decompose faster. Usually, two ages of raw litter are not discernible under *Scaevola* trees as they are under *Messerschmidia*. *Scaevola* litter at this site contained 24% of the ^{137}Cs concentration found in mature green leaves, which is twice the level found in old *Messerschmidia* litters. *Scaevola* apparently can retain radioactivity in its leaves longer as they decompose.

The general trends and patterns of radioactivity previously described are repeated in samples collected later in 1975 and in 1976 (Table 10). A new sample was collected for the first time in February 1976: the branch tip of the tree from which leaves are being collected. That high concentrations of ^{137}Cs

Table 9. Radionuclide concentrations in soil near trench BDFP-5.

Depth of sample, cm	pH	Organic matter, %	pCi/g dry wt.						
			^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{241}Am
0-2.5	8.3	7.0	0.22	22	4.7	170	0.20	18	32
2.5-7.5	8.6	4.7	0.51	7.0	2.0	94	0.33	5.7	12
7.5-15	8.6	5.0	0.46	1.6	0.9	31	0.08	–	2.3
20-30	9.2	3.6	0.70	0.04	–	0.25	0.03	–	–
35-46	9.5	3.1	0.47	–	–	0.06	–	–	–
71-76	9.5	4.3	–	–	–	0.07	–	–	–

Table 10. Radionuclides in soil and plant samples collected at the Lee site from February 1975 to October 1976.

	pCi/g dry wt.							
Sample	^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{207}Bi	^{241}Am
				February 1975				
Messerschmidia green leaves, growing tips	17	–	–	520	–	–	–	–
Messerschmidia green leaves, basal	12	–	–	900	–	–	–	–
Messerschmidia recently fallen yellow leaves	8.7	–	–	580	–	–	–	–
Messerschmidia young brown litter	3.9	–	–	370	–	–	–	–
Messerschmidia old gray litter	2.6	0.5	–	97	0.2	0.6	–	1.7
Messerschmidia entire litter layer, 30.5 × 30.5 cm	2.8	0.2	–	45	–	–	–	0.7
Soil under *Messerschmidia* 0-7.5 cm 12% om	–	1.7	0.38	40	0.7	2.3	0.5	1.8
Soil under *Messerschmidia* 7.5-15 cm 5.8% om	–	2.7	–	47	1.1	4.5	–	4.0
Scaevola green leaves	18	0.3	–	110	–	–	–	–
Scaevola young litter	5.7	0.3	–	80	–	–	–	–
Scaevola old litter	1.3	1.2	–	25	0.3	0.7	0.4	1.4
				July 1975				
Messerschmidia Tree No. 1								
Green leaves, growing tips	21	0.2	–	630	–	–	–	–
Green leaves, base of cluster	19	–	–	710	–	–	–	–
Yellow leaves, recently fallen	8.1	–	4.2	650	–	–	–	0.8
Brown litter, young	4.1	–	–	440	–	–	–	–
Gray litter, old	1.4	0.5	–	100	–	0.2	–	–
Litter fallen on plastic bag	1.5	–	0.7	150	–	–	–	0.9
Litter in 3 trays	2.0	–	–	200	–	–	–	–
Litter in plastic bag	2.5	–	0.2	77	–	–	–	–
Messerschmidia Tree No. 2 green leaves, whole cluster	13	–	–	120	–	–	–	–
Litter, total layer, 50 × 50 cm	3.4	–	–	46	–	0.1	–	–
Litter fallen on plastic bag	2.8	0.1	–	43	–	–	–	–
Litter in 3 trays	2.6	0.1	0.3	52	–	0.1	–	–
Litter in bag	3.4	0.2	–	24	–	–	–	0.3
Fine humus, below leaves 1 in.	1.91	–	0.4	50	–	–	–	0.6
Fine humus, below leaves 2 in.	0.7	3.0	0.8	52	–	24	–	4
				February 1976				
Lee site, *Messerschmidia* Tree No. 1								
Green leaves	11	–	–	630	–	–	–	–
Old leaves	4.4	–	–	590	–	–	–	–

Table 10. (Continued)

Sample	pCi/g dry wt.							
	^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{207}Bi	^{241}Am
Branch tips	11	–	–	890	–	–	–	–
Yellow leaves	6.6	–	–	510	–	–	–	–
Young litter	4	–	–	420	–	–	–	–
Old litter	–	0.1	–	160	–	–	–	–
Litter tray No. 1 under tree	–	–	–	290	–	–	–	–
Litter tray No. 2, 3	3.4	–	–	350	–	–	–	–
Litter tray No. 4 and 5	2.7	–	–	250	–	–	–	–
Litter layer 50 × 50 cm	–	0.04	–	200	–	–	–	0.8
Humus below litter, 5 cm	–	2.7	–	78	0.7	4.1	0.4	16
Humus below litter, 10 cm	–	1.3	–	32	0.4	1.4	0.9	4.5
Lee site, *Messerschmidia* Tree No. 2								
Green leaves	10	–	–	130	–	–	–	–
Branch tips	–	–	–	190	–	–	–	–
Litter layer-A 50 × 50 cm	2.3	–	–	51	–	–	–	–
Litter layer-B 50 × 50 cm	1.6	–	–	52	–	–	–	–
Litter tray No. 2 under tree	4.5	–	–	89	–	–	–	–
Litter tray No. 1 under tree	2.6	–	–	64	–	–	–	–
Litter tray No. 4 under tree	4.2	–	–	100	–	–	–	–
Litter tray No. 5 under tree	–	–	–	90	–	–	–	–
Humus layer 50 × 50 cm	–	1.9	–	15	0.3	0.8	1.7	2.0
				October 1976				
Lee site Vegetation								
Messerschmidia 1, green leaves	20	–	–	650	–	–	–	–
Messerschmidia 1, litter 50 × 50 cm	–	0.5	–	100	–	0.7	–	0.9
Messerschmidia 1, litter on netting	–	–	–	175	–	–	–	–
Messerschmidia 1, green leaves	16	–	–	125	–	–	–	–
Messerschmidia 2, litter 50 × 50 cm	–	0.3	–	30	–	0.2	–	0.6
Messerschmidia 2, litter 50 × 50 cm	–	1.4	–	18	–	1.4	–	0.5
Messerschmidia 2, litter on netting	1.7	–	–	40	–	–	–	–
Morinda, green leaves	11	–	–	170	–	–	–	–
Morinda, fruit	14	–	–	210	–	–	–	–
Pluchea odorata, green leaves	12	–	–	13	–	–	–	–
Lee site, Tree No. 2								
Humus layer, 5 cm 50 × 50 cm	–	0.7	–	18	0.2	0.5	0.8	1.0
Humus layer, 5 cm 50 × 50 cm	–	1.4	–	11	0.3	0.9	1.6	2.7

Table 11. Profile of litter radioactivity at Lee site, Engebi Island for *Messerschmidia argentea* tree 2.

Sample	^{137}Cs concentrations pCi/g	pCi/m^2	Litter biomass, g/m^2
Surface whole litter beneath tree dried leaves	46	9.5×10^4	2100
Finely divided humus, beneath litter, no whole leaves evident, 0-2.5 cm depth	50	2.0×10^5	3,990
Finely divided humus with some coral fragments, 2.5-5.0 cm depth	52	3.7×10^5	7,100
Total litter/humus layer ^{137}Cs radioactivity and biomass		6.6×10^5	13,000
		(0.66 μCi/m^2)	(13 kg/m^2)

were present in the branch tips was suggested from samples taken in October 1975. Branch tips, the succulent young wood on which most of the leaves are borne, had 1.4 X as much ^{137}Cs/g dry wt. as the green leaves from the same branch and tree.[9] This was observed in both *Messerschmidia* trees (Nos. 1 and 2) at the Lee site.

AEN-2 Well Site

Plant and soil samples were collected at the AEN-2 site, midway on the old airstrip at the northern end of the island (Table 12). Measurements of radioactivity in the lens-water at this site are now being made.[10] Leaves were collected from a large *Messerschmidia* tree with a 10.5-m-diam canopy. The ^{137}Cs concentration increased with leaf age while the ^{40}K activity decreased, probably because before leaves began to age, the plant had remobilized leaf potassium. For example, newly fallen yellow leaves had lost 50% of their ^{40}K concentration and essentially none of the ^{137}Cs content compared with the mature green leaf. The large, integrated aged litter sample collected beneath the canopy area had 63% of the ^{137}Cs activity of newly fallen leaves, indicating its rapid loss from the freshly fallen litter.

Dodder (*Cythya filiformis*) growing parasitically on the *Messerschmidia* tree at the AEN-2 site had essentially the same ^{137}Cs concentration as did the tree, but a low concentration of ^{60}Co, which was not detected in the leaf sample from the tree. Cobalt-60 was also detected in the tree litter samples collected beneath the *Messerschmidia* but not in any of the leaf samples.

The organic soil beneath the *Messerschmidia* at the AEN-2 site was sampled to 30-cm depth. The pH was essentially uniform throughout this depth but the organic matter content decreased gradually throughout the 30-cm depth. The highest ^{137}Cs concentrations were in the 0-15 cm stratum and were 14% of those concentrations in mature green leaves (7.1 X). Likely, the 15-25 cm stratum, a vescicular and weakly cemented layer, represented a phosphatic deposit derived from bird manure.[11] The pH of this layer was higher than any layer sampled below or above it.

A *Scaevola* tree 7.6 m north of the large *Messerschmidia* tree at AEN-2 was sampled and showed a similar distribution of radioactivity in its leaves, litter, and sub-canopy soil. The maximum concentration of ^{137}Cs in leaves as 23 X the average concentration in the 0-15 cm stratum of the soil. Cobalt-60 was detected in *Scaevola* leaves and litter but not in the soil beneath the litter, suggesting a rapid recycling of this radionuclide.

Leaves were also collected from large shrubby growths of *Pluchea odorata*, which have overgrown the runway in the area adjacent to the AEN-2 site. *Pluchea* in this area had the highest ^{137}Cs concentration observed in any plant on Engebi Island in the 1972-73 survey. The concentrations of ^{137}Cs in this *Pluchea* stand were also the highest recorded in any plant during January 1975 (1975 819 pCi/g; 1972, 1553 pCi/g). If we use a mean soil ^{137}Cs concentration between the *Messerschmidia* and *Scaevola* trees, the ^{137}Cs vegetation/soil concentration ratio for *Pluchea* is 28 X.

Vegetation/soil concentration ratios are important in determining the transfer of radioactivity from soil to man. Because of the physiological mechanisms associated with the uptake of radionuclides from the soil and their subsequent translocation in the transpiration stream to leaf and fruit, concentration factors in atoll plants range

Table 12. Radionuclide concentrations in soil and plant samples collected at the AEN-2 well site.

Sample	^{40}K	^{60}Co	^{125}Sb	^{137}Cs	^{152}Eu	^{155}Eu	^{207}Bi	^{241}Am
				January 1975				
Messerschmidia								
Young green leaves	19	–	–	190	–	–	–	–
Old green leaves	15	–	–	250	–	–	–	0.30
Recently fallen yellow leaves	9.5	–	–	250	–	–	–	–
Litter layer, canopy area	2.8	0.17	–	94	–	–	–	0.25
Litter layer, 61 × 61 cm (A)	2.4	0.15	–	86	–	–	–	–
Litter layer 61 × 61 cm (B)	4.3	0.1	–	110	–	0.15	–	–
Soil under *Messerschmidia*								
0-5 cm, pH-8.1, 10.3% om	–	2.5	0.6	36	0.08	1.8	0.73	2.1
5-15 cm, pH-8.3, 6.7% om	–	3.4	1.2	35	0.13	2.3	2.3	2.4
15-25 cm, pH-8.6, 5.0% om	–	0.2	0.3	5.5	–	–	–	0.08
25-30 cm, pH-8.3, 4.7% om	–	0.7	0.5	11	–	0.40	0.11	0.86
Cythya filiformis dodder, parasitic on *Messerschmidia*	20	0.4	–	280	–	–	–	–
				October 1975				
Pluchea odorata green leaves	18.1	0.05	–	819	–	–	–	–
Messerschmidia green leaves	19	–	–	191	–	–	–	–
				February 1976				
Messerschmidia green leaves	12	–	–	160	–	–	–	–
Scaevola green leaves	13	–	–	145	–	–	–	–
Messerschmidia branch tips	14	–	–	170	–	–	–	–
Pluchea green leaves	9.6	–	–	490	–	–	–	–
Messerschmidia litter layer 50 × 50 cm	–	–	–	51	–	–	–	–
				October 1976				
Pluchea green leaves	9.6	0.31	–	1200	–	–	–	–
Messerschmidia green leaves	14	–	–	150	–	–	–	–

from 4 to 30 X (Table 12). From the data in this table, ^{137}Cs does not behave entirely like potassium in the metabolism of atoll plants because of differences in ^{40}K and ^{137}Cs concentrations between the leaf, litter, and soil. There is little potassium in the soil, except for raw litter layers from which it is rapidly leached and apparently reabsorbed by the root system of the plant. Cesium-137 concentration ratios for plants and soils collected on Engebi Island are shown in Table 13.

At the AEN-2 well site, ^{137}Cs concentration ratios range from ~5 (*Messerschmidia*) to 17 (*Scaevola*). At trench BDFP-2, *Scaevola* also showed a higher ratio for ^{137}Cs, and soil concentrations under *Scaevola* were only 45% of the levels under *Messerschmidia*. At AEN-2, soil ^{137}Cs concentrations under both trees were similar. *Messerschmidia* ^{137}Cs concentration ratios were usually <10 in this series of measurements, but at the Lee site, a ratio of 23 was observed in mature, green *Messerschmidia* leaves. More methodical sampling of this type is needed to determine the ranges of concentration ratios in these species and in food plants grown on the same soils.

Table 13. Vegetation/soil concentration ratios for ^{137}Cs.

Sample	Vegetation/soil ^{137}Cs concentrations, pCi/g[1] dry wt.	Ratio
Messerschmidia (AEN-2) young leaves/soil 0-5 cm	190/36	5.3
Messerschmidia (AEN-2) old leaves/soil 0-5 cm	252/36	7
Messerschmidia (trench BDF-2) green leaves/soil 0-5 cm	514/93	5.5
Messerschmidia (trench BDF-1) green leaves/soil 0-5 cm	283/64	4.4
Messerschmidia (Lee site) green leaves/soil 0-7.5 cm	900/40	23
Scaevola (AEN-2) green leaves/soil 0-5 cm	530/32	17
Scaevola (trench BDF-2) green leaves/soil 0-5 cm	540/42	13

Litter Deposition and Decomposition Measurements in Follow-up Research Program

Litter deposition and decomposition studies are important because it is from this organic compartment that radionuclides are recycled and re-enter the terrestrial biota. If leaching losses from the litter and surface soil strata into the ground water lenses were high, terrestrial radioactivity levels would decrease rapidly. From data now available on litter breakdown, release of incorporated radionuclides and subsequent radionuclide distribution in the soil suggest a rapid recycling of radionuclides such as ^{137}Cs and ^{60}Co.

Litter decomposition was studied in a litter bag experiment at the Lee site.[12] The results of the litter deposition and decomposition study are shown in Tables 14 and 15. Three litter bags were loaded with 1 kg of fresh *Messerschmidia* leaves and placed under the same tree. A sub-sample was taken for radionuclide analysis. The bags were collected in July 1975, after they had been in the field for six months. The bag contents were dried, weighed, and assayed for gamma-emitting radionuclides. The litter-bag leaf decomposition data indicate that the leaves have a short half-life, but this involves only the early physical breakdown of the leaf and not the complete mineralization of the litter. The data do indicate, however, that radioactivity is rapidly lost from the leaf however complete decomposition is at the end of this time (six months). We also found that 99% of the radioactivity in the leaf and 93% of the organic matter in the litter bag had been removed in the six-month period. The litter did not become mineralized in this period but became physically reduced in size so that it fell or was washed from the bags. Litter was collected from measured areas to determine the total litter biomass in the raw litter layer and to measure litter deposition rates. The data in Table 14 show two values obtained in January and July 1975 at Lee site.

Leaf-fall or litter deposition on the bags during this period indicated that an average of 475 g/m^2 fell from the tree during the six months. Litter deposition in the plastic trays was slightly less, 269 g/m^2. Leaves probably were lost from the smooth plastic trays from the ground-surface winds.

January to March is the driest period of the year at Enewetak Atoll, and leaf-fall from water-depletion stress may be expected to be the highest during or subsequent to this time. In years of severe drought, some trees such as *Pisonia grandis* may lose all of the canopy during this period. In July, there was an accumulation of 887 g/m^2 raw litter.

Table 14. Litter deposition and decomposition measurements Lee site on Engebi Island.

Measurement	^{40}K (pCi/g)	^{60}Co (pCi/g)	^{137}Cs (pCi/g)	Litter biomass, g/m^2	^{137}Cs, pCi/m^2 × 10^4
Litter deposition: January-July 1975					
Messerschmidia Tree 1	1.5	0.1	150	540	8.0
Messerschmidia Tree 2	2.8	0.1	43	415	1.8
Tray Collections: January-July 1975 (3/tree)					
Messerschmidia Tree 1	2.0	0.2	200	270	5.5
Messerschmidia Tree 2	2.6	0.1	52	270	1.4
Unit area collections (50 × 50 cm areas)					
Messerschmidia Tree 2, Jan 1975	2.8	0.2	45	1350	6.0
Messerschmidia Tree 2, July 1975	3.4	–	46	2100	9.5

Table 15. Litter decomposition measurements January-July 1975 using litter-bag method.

Site/measurement	Total pCi in bag Jan/July	pCi/g[1] Jan 75	pCi/g[1] Jul 75	dry wt., g Jul 75	dry wt. loss, %	pCi lost, %
Messerschmidia Tree 1 1000 g wet wt., green leaves 12% dry wt.	$\frac{7.1 \times 10^5}{6.3 \times 10^3}$	710	77	77	36	99
Messerschmidia Tree 2 1000 g wet wt., green leaves 12% wet wt.	$\frac{1.2 \times 10^5}{1.5 \times 10^3}$	120	24	62	48	99

The biomass of the litter layer increased by this value from January through July. This is almost twice the value obtained by measuring leaf-fall on the litter bags (475 g/m ^{2}). Some areas beneath the trees may collect more litter than others because of micro-climatic effects such as the windrowing of litter by prevailing winds; twofold variations are not large when measuring ecological events such as leaf-fall.

The average leaf-fall for January through July on the litter bags was 474 g/m ^{2} (~950 g/m ^{2}y), and the average litter biomass was 1651 g/m ^{2}, indicating that about 30% of the litter biomass fell in six months or about 60% in one year. Because litter layers appear to be in equilibrium with deposition and decomposition, we may assume a 1 to 1.5 y half-life of the litter biomass.

Litter deposition measurements were continued in February 1976 and are shown in Tables 16 and 17. Two *Messerschmidia* trees at the Lee site were measured with five trays beneath each canopy to collect the litter fall. Tree 1 had a litter fall of 388 g/m ^{2}, but tree 2, 10 m away, had a fall of 547 g/m ^{2}; both fell since July 1975. Tree 2 is

Table 16. Litter deposition measurements in February 1976 from Lee site.

Source	In tray, g	Cesium-137 g/m^2	pCi/g	pCi/m^2
Messerschmidia tree 1				
Tray 1	99.5	529	290	1.6×10^5
2 plus 2	128	340	345	1.2×10^5
4 plus 5	137	365	253	9.2×10^5
Mean =	73	388		
Messerschmidia tree 2				
Tray 1	69	367	64	2.3×10^4
2 plus 3	175	465	89	4.2×10^4
4	147	782	103	8.0×10^4
5	123.3	666	90	5.9×10^4
Mean =	102.9	547		
Overall mean		501 ± 167		2×10^5
Previous litter-fall measurements (g/m^2):				
Litter-fall on plastic bags, Jan-July 1975	475			
Litter-fall in trays, Jan-July 1975	269			
Litter-fall in trays, July-Feb 1976	501			

Table 17. Litter mass measurements in February 1976.

Site and tree	g (50- × 50-cm quadrant)	g/m^2
Lee site		
Tree 1	355	1420
Tree 2	475	1900
Biomass tree 1 A	333	1332
B	260	1040
Biomass tree 2 A	301	1204
B	355	1420
Well AEN-2 site	252	1008
Trench BDFP-1	419	1676
Mean =	344	1375 ±304

somewhat more protected from prevailing winds and it is possible that Tree 1 trays lost leaves from the winds. The overall mean litter fall during the 6- to 7-month period was 500 g/m^2.

To reduce wind losses and sample a larger area beneath the canopy, a large litter tray made of 12- × 12-mm wire mesh was placed in the field in February 1976. Table 18 is a summary of all areal litter sample collections made to Febarury 1976, including those made in the wire trays. The overall mean litter biomass from the 50-cm-square samples is 1376 ± 305 g/m^2. Annual litter deposition ranges from 700-1600 g/m^2/y beneath these trees, which suggests there is a general equilibrium between litter fall and litter biomass, and that the litter cycle is not much longer than one year.

Bray and Gorham [13] have discussed litter production in forests of the world, and presented values for tropical forests in Africa, Colombia, and Malaya. They found annual litter production to be between 550-1530 g/m^2·y (5.5-15.3 ton/ha·y) in tropical forest. Our value for tropical woodland vegetation at Enewetak Atoll receiving 125 cm of rainfall per year is 950 g/m, which is in the middle of this range. However, our measurements were made during January-July, a dry period at Enewetak Atoll, and this could have affected our results. Nevertheless, *Messerschmidia* trees grow continuously and have not shown signs of severe water stress, so that the January-July value may be characteristic of the annual cycle.

Humus layers beneath the litter layer must also be in equilibrium with the litter, but the deposition and turnover in them are difficult to measure. Humus biomass is generally larger per unit area than the litter, suggesting a longer decomposition time for humus. The litter decomposition studies conducted to date indicate a rapid physical breakdown of leaf biomass when it falls from the tree, and an equally rapid release of its contained radionuclides.

Table 18. Summary of litter deposition and mass measurements.

Litter measurement		g/m^2
Litter fall:		
In trays		
January-July 1975		269
January-July 1975		270
July 1975-February 1976		529
		340
		365
		367
		465
		782
		666
	Mean =	449
On litter decomposition bags		
January-July 1975		535
		415
	Mean =	475
Litter mass:		
January 1975		1348
July 1975		2095
February 1976		1420
		1900
		1332
		1040
		1204
		1420
		1008
		1676
	Mean =	1444

CONCLUSIONS

The ecological samples discussed in this report were collected to obtain information on the natural cycling of radionuclides on Engebi Island at Enewetak Atoll. Data obtained in the 1973 radiobiological survey [1] indicated that concentrations of radionuclides in terrestrial plants often exceed the concentrations in the soil surface (0-25 cm) strata.

Our data indicate that, in the five trenches we sampled, most of the soil radioactivity occurs in the surface (0-25 cm) and is generally associated with the organic portion of the soil. This layer is weakly acidified and variably stained with organic matter from light to dark brown. Organic matter content in the surface soil (0-10 cm) may be as high as 10-15%, with an average of ~6%. The pH of the soils with higher organic content range from 7.8-8.0. Soil samples taken at depths of >50 cm had pH values as high as 9.0.

The relationships between leaf, litter, humus, and surface soil radionuclide concentrations indicate a rapid recycling of the radionuclides released from recently fallen leaves (litter) by rainfall leaching. By the time litter has become finely divided organic matter or humus, it has lost nearly all of its ^{137}Cs, but has acquired small amounts of ^{60}Co, ^{125}Sb, $^{152\text{-}155}$Eu, and ^{241}Am. Radionuclide concentrations at depths of 100 cm or more are at very low levels, <1 pCi/g for ^{137}Cs, the most prevalent radionuclide. This suggests that most of the radioactivity released by soil-surface reactions (leaching of the litter and humus) is either absorbed by plant roots or is complexed into the soil's organic stratum. When rainfall is heavy, which would produce through-flow of soil water, radionuclides will be lost to the ground water or lenses. Radioactivity can escape from the two surface sinks (plant root absorption and soil complexation) because radionuclides are present in the lenses and their concentrations fluctuate with time.[10] A lens-water well on Engebi Island (AEN-2) had a ^{137}Cs concentration of 38 pCi/g. In every soil profile we examined, dissolved organic matter, leached from the litter layer, was complexed by the upper 25 cm of the soil column.

Litter studies indicate that ^{137}Cs remains a short time (12-16 months) in the litter; the release of ^{137}Cs from new litter into the humus layer and the surface soil (root) zone is very rapid. Studies of the series from fallen senescent leaves to raw litter to humus beneath the litter layer demonstrate that only 4.5% of the maximum green leaf radionuclide concentration remains after decomposition of the leaf has reduced it to granular humus. Litter decomposes rapidly in the early stages, and more than 90% of the litter-contained radionuclides are released in less than 6 months. By this time, all of the ^{40}K of the organic matter has been mobilized and has been reabsorbed by the plant because we did not detect it in the soil beneath the litter and humus.

The absorption of radionuclides leached from living leaves is suggested by the presence of ^{60}Co, ^{125}Sb, and $^{152\text{-}155}Eu$ in the litter and humus at detectable levels; however, these radionuclides were not measurable in the soil beneath the litter or in the green foliage.[8]

Our measurements are preliminary and do not represent all seasons on Enewetak. The general trend, however, is that organic matter and its incorporated radioactivity is rapidly being cycled in the Engebi terrestrial ecosystem. Studies being currently conducted in the radioecological program show that gross biomass production is similar to the rate of litter production and decomposition. The rapid feedback of organically bound radionuclides into the soil and the rhizosphere of the Engebi's natural vegetation has considerable significance for man in his use of this atoll environment.[14,15]

Further studies will be directed toward quantitating litter fall, decomposition and growth rates, and the release of incorporated radionuclides from the litter and organic soil stratum. Lysimeters have been installed in several trenches to collect the water moving through the soil. Samples of soil water flowing in the porous soil during heavy rainfall can tell us the amount of water and radioactivity leaving the soil surface environment toward the lens-water systems. The lens-water radionuclides represents those radionuclides lost from the terrestrial ecosystem and it is believed that lens-water losses account for the majority of radionuclides lost from the Enewetak ecosystem.

The conservation of potassium and radionuclides by the vegetation minimizes losses of radioactivity from the terrestrial ecosystem, and is responsible for the almost constant levels of radionuclides observed in some of the plants we sampled. Seasonal patterns of radionuclide concentrations, until they have been established and related to rainfall distribution, will confound measurements of radionuclide residence time in the Engebi environment. Once the trends of radioactivity in the terrestrial compartments have been quantitated,[16] reasonable estimates of environmental half-lives for the significant radionuclides may be made and used to make realistic dose assessments for the Enewetak peoples subsisting by some form of tropical agriculture.

ACKNOWLEDGMENT

We would like to acknowledge the assistance of the following LLL personnel: William Phillips, John Rehder, Cynthia Conrado, and William Burke. Members of Pacific Area Support Office, DOE, Honolulu, Hawaii, have also aided this program in the many logistic problems that arose in conducting ecological research at these remote sites. Also, we wish to thank Roger Ray, Nevada Operations Office, DOE, for encouragement and assistance in many matters related to this program.

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